

## **EXECUTIVE SUMMARY: Analysis of Particulate Matter Impacts for the City of Alexandria, Virginia**

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This report provides a detailed look at the influence of five power plants on air pollution and health in Alexandria, based on a previously published regional analysis. The focus is on fine particulate matter (PM<sub>2.5</sub>), since studies have shown that respiratory and cardiovascular health are affected by PM<sub>2.5</sub> at current outdoor levels in Alexandria.

We modeled sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), and directly-emitted (primary) PM<sub>2.5</sub> emissions from Benning, Chalk Point, Dickerson, Possum Point, and Potomac River. We considered both current emissions and what the plants would emit if Best Available Control Technology were used.

The Potomac River plant contributes about 0.2-0.6 µg/m<sup>3</sup> of PM<sub>2.5</sub> in Alexandria (where outdoor levels are about 13-15 µg/m<sup>3</sup>). The variation within Alexandria is mostly from primary PM<sub>2.5</sub>, since the secondary particulate matter (formed from SO<sub>2</sub> and NO<sub>2</sub> emissions) is more uniform across the city. The maximum impact of the Potomac River plant occurs in Washington, about 4 km from the plant.

When we consider all five power plants together, they contribute about 0.6-1.1 µg/m<sup>3</sup> of PM<sub>2.5</sub> in Alexandria. The five power plants contribute about 2.3 deaths, 0.7 cardiovascular hospital admissions, and 1.2 pediatric asthma emergency room visits per year within Alexandria. This is about 1% of the total regional impacts, given that only 0.2% of the regional population is found in Alexandria. If Best Available Control Technology were used, it would eliminate 1.7 deaths, 0.5 cardiovascular hospital admissions, and 0.9 pediatric asthma emergency room visits per year in Alexandria (31% of which are related to Potomac River).

Interpretation of these findings is complex. Although much of the PM<sub>2.5</sub> in Alexandria would remain if these emission controls were implemented, the Potomac River plant is likely the single largest contributor to PM<sub>2.5</sub> in Alexandria. It is also clear that emission control decisions must consider regional impacts if total public health benefits are a concern, but must also evaluate local impacts to ensure that populations are not disproportionately impacted. Our findings cannot provide a definitive policy recommendation, in part because we did not consider control costs and did not conduct detailed near-source modeling necessary to fully understand spatial patterns. However, this report provides some information about the relative importance of local and regional power plants for air pollution in Alexandria, which can be used to inform future policy decisions.

## **Analysis of Particulate Matter Impacts for the City of Alexandria, Virginia**

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### **Background**

In 2002, I published an analysis with colleagues at Harvard School of Public Health that evaluated the public health benefits associated with hypothetical emission reductions at five power plants in the Washington, DC area (Levy *et al.*, 2002a). This publication documented the impacts that emission controls at these five power plants would have on fine particulate matter (PM<sub>2.5</sub>) levels in the region, and estimated the associated health benefits (including reduced premature deaths, hospital admissions for cardiovascular disease, and emergency room visits for pediatric asthma).

Since that work was completed, there has been interest in a more comprehensive understanding of the implications of the study for the City of Alexandria, Virginia. Alexandria is home to the Potomac River power plant, one of the five plants studied in our analysis, and there are obvious questions about the magnitude of benefits in Alexandria associated with emission controls at Potomac River. There are also broader questions about how these benefits compare with the benefits from controlling other pollution sources, including the other four power plants we studied and other sources of PM<sub>2.5</sub>.

In this report, I attempt to provide more detailed information aimed at helping citizens and decision makers in Alexandria to appropriately interpret the results of our study and make the best public policy decisions possible. I first provide some general background about PM<sub>2.5</sub> in and around Alexandria and about the five power plants we studied. I then estimate the contribution of the Potomac River power plant to concentrations in Alexandria and across the region, and I compare this with the contributions from the other four power plants studied. I calculate the health impacts of each power plant within the City of Alexandria, and estimate the benefits of applying emission control technology. I conclude with a general discussion of the implications of these findings.

It is important to state upfront that the evidence in this report does not by itself imply that any specific policy decisions should be made, in part because I only consider a subset of the pertinent questions. For example, the costs or feasibility of controls are not addressed, nor are the full array of impacts from the plants. This report does not provide specific policy recommendations, but rather aims to provide quantitative, science-based evidence that can be used to inform decisions.

## What is PM<sub>2.5</sub>, and why are we concerned about it in Alexandria?

Before discussing the findings of our study, it is worth providing some basic background about the air pollutant of interest – fine particulate matter (PM<sub>2.5</sub>). Although other air pollutants influence public health, our study (and the findings reported below) only addresses the impacts of PM<sub>2.5</sub>.

The formal definition of particulate matter is any solid or liquid substance suspended in the air. It therefore includes a large number of different constituents, of different sizes and different chemical composition. Particulate matter is often described by its size, considering all different constituents together. PM<sub>2.5</sub> refers to the fraction of particles that are less than 2.5  $\mu\text{m}$  in diameter (there are one million  $\mu\text{m}$  in a meter). This is a definition of interest because particles this size are best able to travel to the lower portions of the lung, and would be most likely to contribute to health effects.

Particulate matter can exist in one of two basic forms. It can either be directly emitted from a source, or it can be created through chemical reactions in the atmosphere. Directly emitted particulate matter, like fly ash or carbon particles from diesel vehicles, is known as primary particulate matter. Particulate matter formed through chemical reactions, like sulfate and nitrate particles formed due to sulfur dioxide (SO<sub>2</sub>) and nitrogen oxide (NO<sub>x</sub>) emissions, is known as secondary particulate matter. I will use these terms throughout the report.

Fine particulate matter (PM<sub>2.5</sub>) is of interest in this context for two major reasons. First, there has been extensive health evidence linking PM<sub>2.5</sub> with a variety of adverse health impacts, including respiratory symptoms, hospitalizations for respiratory or cardiovascular disease, and premature mortality. The evidence supporting this relationship is too extensive to discuss in detail here, but some of the major studies are referenced in our article (Levy *et al.*, 2002a), and many others are documented in the US EPA Criteria Document (US Environmental Protection Agency, 2003a).

For the purpose of this report, an obvious question is whether PM<sub>2.5</sub> in Alexandria would be expected to contribute to public health impacts. To answer this question, we need to know two things: what is the composition and concentration of PM<sub>2.5</sub> in Alexandria, and does the health evidence show that this level of PM<sub>2.5</sub> has health implications?

Regarding the first question, I am not aware of detailed assessments of the PM<sub>2.5</sub> composition in Alexandria itself, but analyses based in the Washington, DC region are informative about general concentration patterns. Speciated PM<sub>2.5</sub>

data are available at <http://www.epa.gov/air/oaqps/pm25/analysis.html> for a site in Washington, DC and for a site in Richmond, VA. Figure 1 depicts the composition of PM<sub>2.5</sub> at these two sites on an annual average basis.

Figure 1: Composition of PM<sub>2.5</sub> in Richmond, VA and Washington, DC.

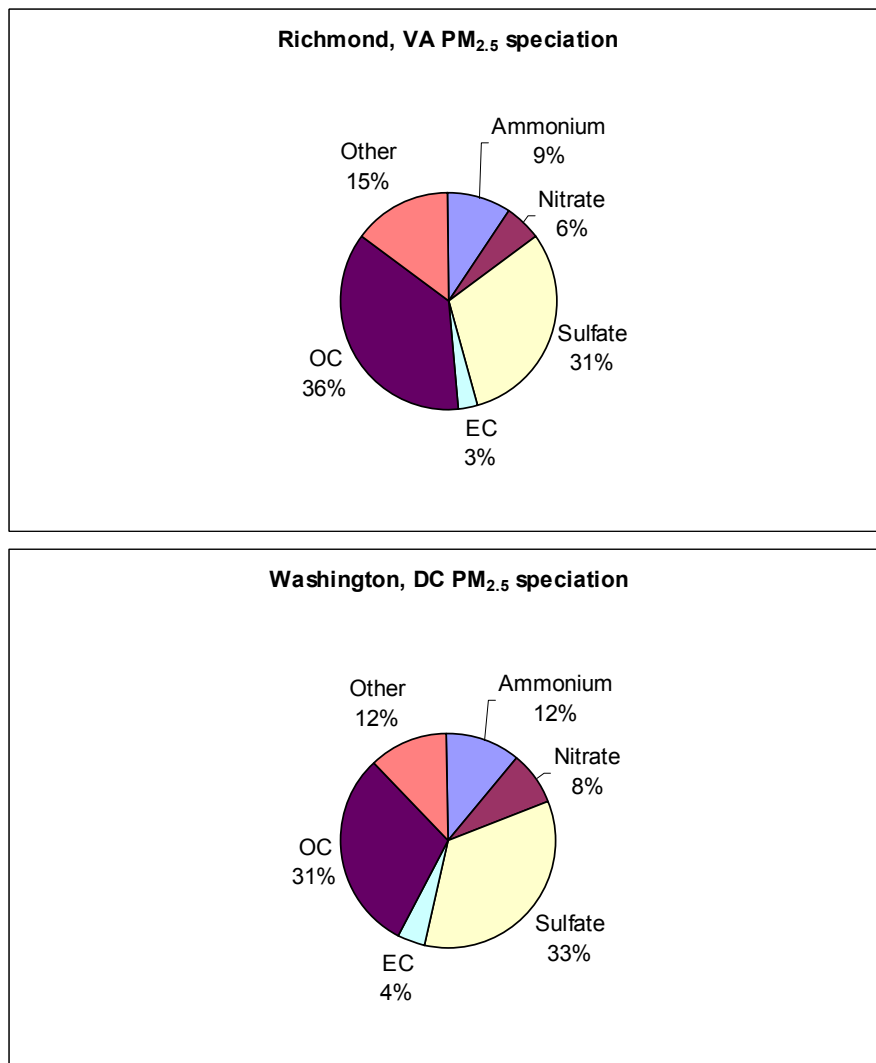


Figure 1 illustrates that in the Washington, DC area, slightly more than one-third of fine particulate matter is related to elemental carbon (EC) or organic carbon (OC), which are generally more strongly associated with motor vehicles than with power plants. About half of PM<sub>2.5</sub> is associated with ammonium, sulfate, or nitrate, which are generally secondarily formed particles often related to power plants. Ammonium sulfate, which dominates the secondarily formed particles, is almost entirely related to power plant emissions. The above figures also demonstrate that the particle composition only varies slightly between settings in close proximity to one another, indicating that these figures likely reasonably capture particle speciation in Alexandria.

Now, what is known about the magnitude of PM<sub>2.5</sub> concentrations in Alexandria? For this, I turn to information from the Virginia Department of Environmental Quality (<http://www.deq.state.va.us/airmon/pm25home.html>). For monitors in the Northern Region of Virginia (including measurements in Arlington, Fairfax, and Loudon Counties), annual average PM<sub>2.5</sub> concentrations consistently ranged between 13 and 15 µg/m<sup>3</sup> from 1999 to 2003. In addition, data from Virginia DEQ consistently demonstrates higher concentrations during the third quarter (July-September) than during other quarters. This pattern is typical in settings where ammonium sulfate comprises a significant portion of PM<sub>2.5</sub>, because sulfate particles form more readily at higher temperatures and more electricity is used during the summer (for air conditioning) than during other seasons. Thus, it is reasonable to assume that annual average PM<sub>2.5</sub> concentrations in Alexandria are approximately 13-15 µg/m<sup>3</sup>, with a pronounced summertime peak.

Turning to the second question above, is there evidence that PM<sub>2.5</sub> concentrations of approximately 13-15 µg/m<sup>3</sup> on an annual average basis could contribute to human health impacts? A critical fact to realize is that, although the National Ambient Air Quality Standard for PM<sub>2.5</sub> (which is currently 15 µg/m<sup>3</sup>) is above these levels, the National Ambient Air Quality Standard (NAAQS) is not meant to be a zero-risk level.

Quoting from the US EPA, "The Act does not require the Administrator to establish a primary NAAQS at a zero-risk level, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety" (US Environmental Protection Agency, 1997). Although many people commonly interpret a NAAQS as a threshold below which no health effects are found, this is not necessarily a correct interpretation. One must look to the health evidence to determine whether current PM<sub>2.5</sub> levels in Alexandria might cause health problems.

Two of the major studies examining mortality risks from long-term exposure to

PM<sub>2.5</sub> are the Harvard Six Cities Study (Dockery *et al.*, 1993) and the American Cancer Society Study (Pope *et al.*, 1995; Pope *et al.*, 2002). In both of these studies, there did not appear to be a threshold for PM<sub>2.5</sub> effects at the pollution levels measured in the studies. In other words, the risk of dying continued to decrease as the pollution level decreased, down to the lowest levels measured in the studies. Annual average PM<sub>2.5</sub> concentrations in the Harvard Six Cities Study ranged between about 11 and 30 µg/m<sup>3</sup>, while the concentrations in the American Cancer Society study ranged between about 9 and 34 µg/m<sup>3</sup> during the initial study (Pope *et al.*, 1995) and between about 6 and 21 µg/m<sup>3</sup> during a later follow-up period (Pope *et al.*, 2002).

Although there is clearly more uncertainty about effects at lower levels, given fewer historical observations, the first draft of the Particulate Matter Staff Paper (US Environmental Protection Agency, 2003b) made the following observations:

- “Studies reporting statistically significant associations in areas where the long-term mean 24-hour PM<sub>2.5</sub> concentrations ranged from approximately 14 µg/m<sup>3</sup> down to 8.5 µg/m<sup>3</sup> provide evidence of PM<sub>2.5</sub>-related total and cardiovascular mortality and emergency department visits related to asthma and cardiovascular illness at levels below the current annual standard” (p. 6-18)
- “Studies conducted in Phoenix (Mar *et al.*, 2000), Santa Clara County, CA (Fairley, 1999) and in eight Canadian cities (Burnett *et al.*, 2000) reported significant relationships between PM<sub>2.5</sub> and mortality where mean PM<sub>2.5</sub> concentrations ranged between 13 and 14 µg/m<sup>3</sup>” (p. 6-18)
- “...staff believes that it would be appropriate to consider a range of PM<sub>2.5</sub> levels for an annual standard that extends down from 15 µg/m<sup>3</sup> to as low as 12 µg/m<sup>3</sup>” (p. 6-19)

Thus, although uncertainty remains, it is reasonable to conclude that PM<sub>2.5</sub>-related health effects could be anticipated in Alexandria at current ambient concentrations.

Where are the five power plants in question, and what are their current emissions?

For our analysis, we evaluated five power plants that were within 50 miles of Washington, DC, and that were grandfathered under the Clean Air Act. This implies that these plants are not required to meet the same emission standards as newer power plants, although there are other regulations they must follow. Basic information about the five power plants is presented in Table 1 (adapted from Table 1 in (Levy *et al.*, 2002a)).

Table 1. Characteristics of power plants evaluated in this study.

	Benning	Chalk Point	Dickerson	Possum Point	Potomac River
Location	Washington, DC	Aquasco, MD	Dickerson, MD	Dumfries, VA	Alexandria, VA
Initial year of commercial operation	1968	1964	1959	1948	1949
Nameplate capacity (megawatts)	580	2046	588	1373	514
Heat input (million BTU, 1999)	3,304,107	85,352,274	33,592,811	28,930,805	32,100,184
Emissions (tons, 1999)					
SO <sub>2</sub>	1,432	57,630	30,637	19,497	17,627
NOx	447	25,222	10,709	5,116	6,893
PM <sub>2.5</sub>	12	304	14	156	106
Emissions (lb/million BTU)					
SO <sub>2</sub>	0.87	1.35	1.82	1.35	1.10
NOx	0.27	0.59	0.64	0.35	0.43
PM <sub>2.5</sub>	0.007	0.007	0.0008	0.011	0.007

A few observations can be made about these data. First, emission rates vary somewhat from year to year, so the contributions of the five power plants would

vary from year to year as well. More explicitly, if there were increases or decreases in emissions since 1999, there would be a corresponding change in concentrations and health impacts. In addition, the target emission rates (defined as the application of Best Available Control Technology) were assumed to be 0.3 lb/million BTU for SO<sub>2</sub>, 0.15 lb/million BTU for NO<sub>x</sub>, and 0.01 lb/million BTU for PM<sub>10</sub>. Looking at the last three rows of the table, meeting this level would be a substantial reduction of both SO<sub>2</sub> and NO<sub>x</sub>. For PM<sub>2.5</sub>, the degree of reduction varies, depending on the current size distribution of primary particulate matter emissions at the five plants.



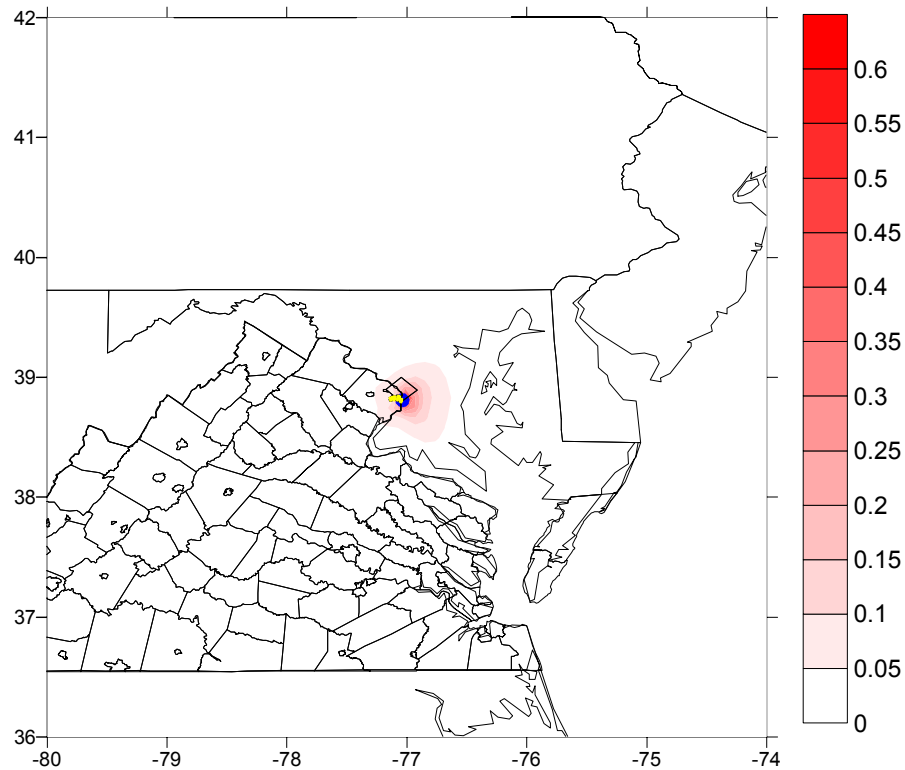
What are the concentration impacts from the Potomac River power plant, in Alexandria and across the region?

When we consider the impacts from the Potomac River power plant, it is helpful to look at this question from a few perspectives. We can consider primary and secondary  $PM_{2.5}$  separately, as well as considering the total  $PM_{2.5}$  impacts, to get a sense of differences in spatial patterns. While we are most concerned about the total, some emission control plans may only address one of the pollutants, so it is helpful to see how the concentration patterns differ. We can also look at concentrations from a regional perspective, or with a “close up” view of Alexandria. When we take the “close up” view of Alexandria, we can include nearby cities (like Washington) to help interpret the findings. By looking at the question in all of these ways, we can gain insight about the magnitude and distribution of impacts from Potomac River.

Before doing this, it is important to understand how the following maps were made and what they mean. The concentrations were estimated for each census tract in Alexandria and nearby areas. Census tracts are subsets of counties that contain about 1,000 to 8,000 people on average. So, our model cannot provide information on finer-scale concentration impacts. The regional maps are “contour plots”, which show the general concentration trends, smoothing out some of the small-scale differences. The Alexandria plots (which also include Washington) show the exact concentration increments in each census tract, so they are less “smooth”. Sometimes, the concentrations in the Alexandria plots seem to follow unintuitive patterns, but this is in part because they are based on the geographic centroid of the census tract and are not estimated across the entire tract. In addition, the figures represent annual average concentrations, so the plume may travel in one direction some of the time and another direction some of the time, which would appear in the figure as higher concentrations in multiple directions. Finally, it is important to keep in mind that the figures below depict the concentrations only associated with the modeled power plant(s), not from all sources.

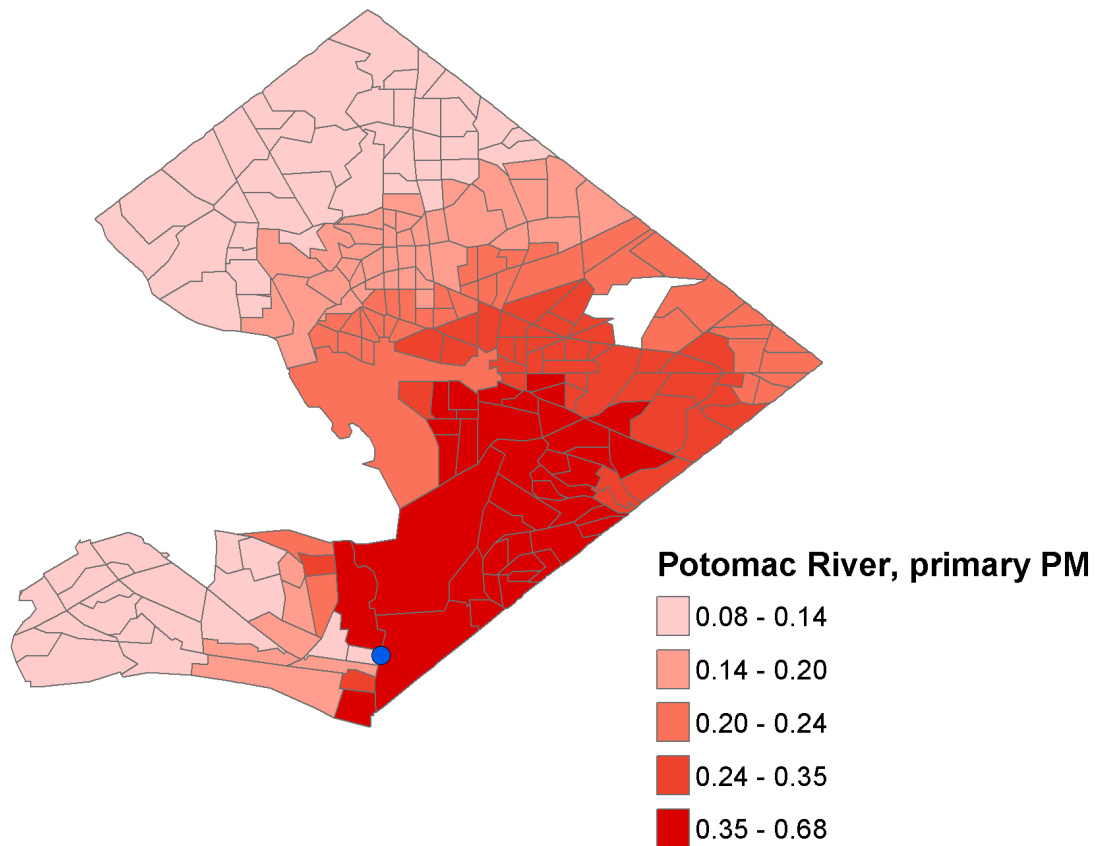
First, we look at primary  $PM_{2.5}$  from the regional perspective. In the following figure, and in all subsequent regional figures, the blue dot represents the Potomac River power plant, the shaded yellow area indicates the City of Alexandria, and the red contours represent the concentration patterns. Figure 2 on the following page shows the annual average primary  $PM_{2.5}$  concentration increments associated with the Potomac River power plant.

Figure 2: Annual average primary PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the model region (in  $\mu\text{g}/\text{m}^3$ ).



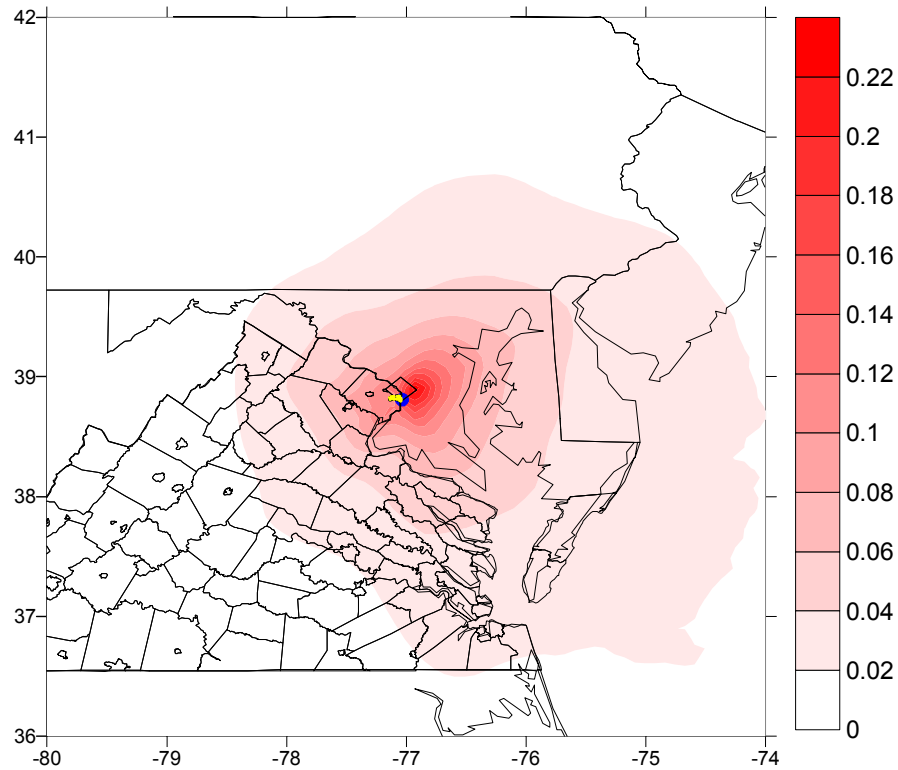
A few observations can be made. First, the concentrations peak close to the source and decrease rapidly with distance. The highest primary PM<sub>2.5</sub> concentration increment is approximately  $0.7 \mu\text{g}/\text{m}^3$ , located within Washington, DC, approximately 4 km from the Potomac River power plant. This is because it takes some time for the plume to reach the ground. As shown in Figure 3, there is a significant primary PM<sub>2.5</sub> gradient across Alexandria, with the concentration increment from Potomac River ranging from  $0.08$ - $0.45 \mu\text{g}/\text{m}^3$ . Higher levels occur in closer proximity to the plant, although the census tract housing the Potomac River plant has relatively lower concentrations.

Figure 3: Annual average primary PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the City of Alexandria and Washington, DC (in  $\mu\text{g}/\text{m}^3$ ).



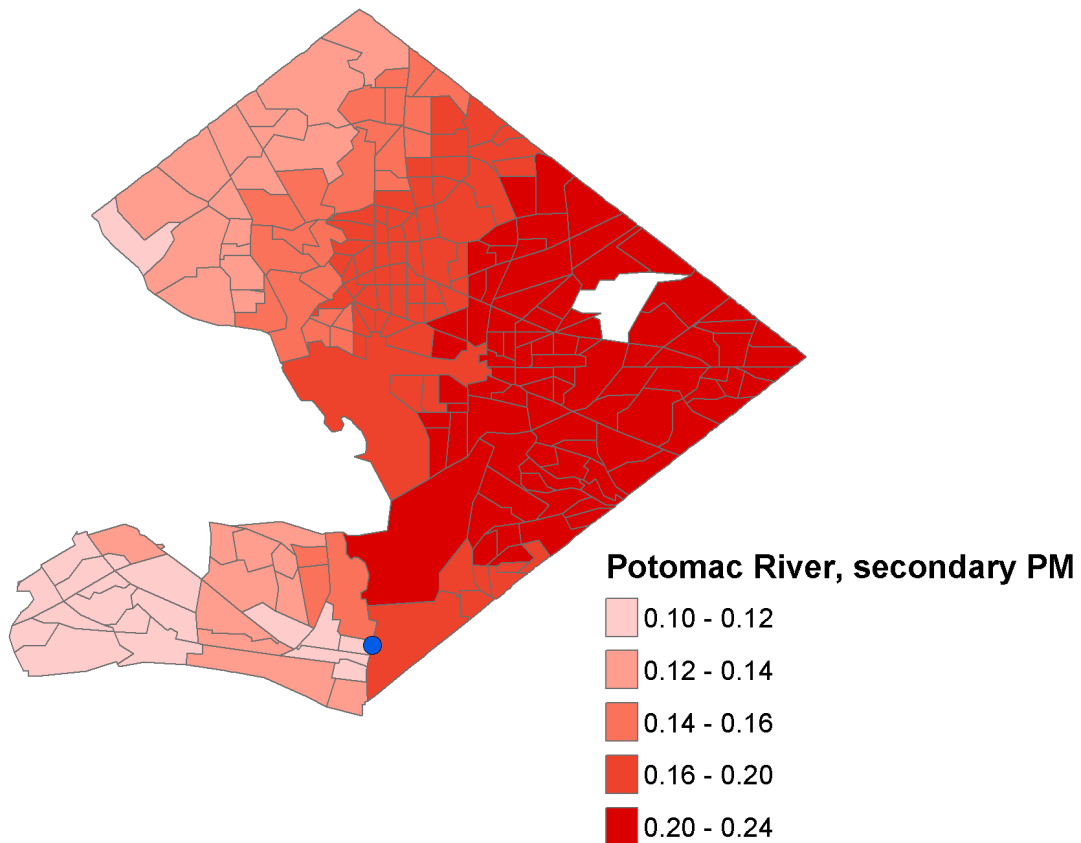
For secondary PM, we would anticipate a lesser concentration gradient, since it takes time to form secondary sulfate and nitrate particles. Figure 4 shows the annual average secondary PM<sub>2.5</sub> concentrations associated with the Potomac River power plant.

Figure 4: Annual average secondary PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the model region (in  $\mu\text{g}/\text{m}^3$ ).



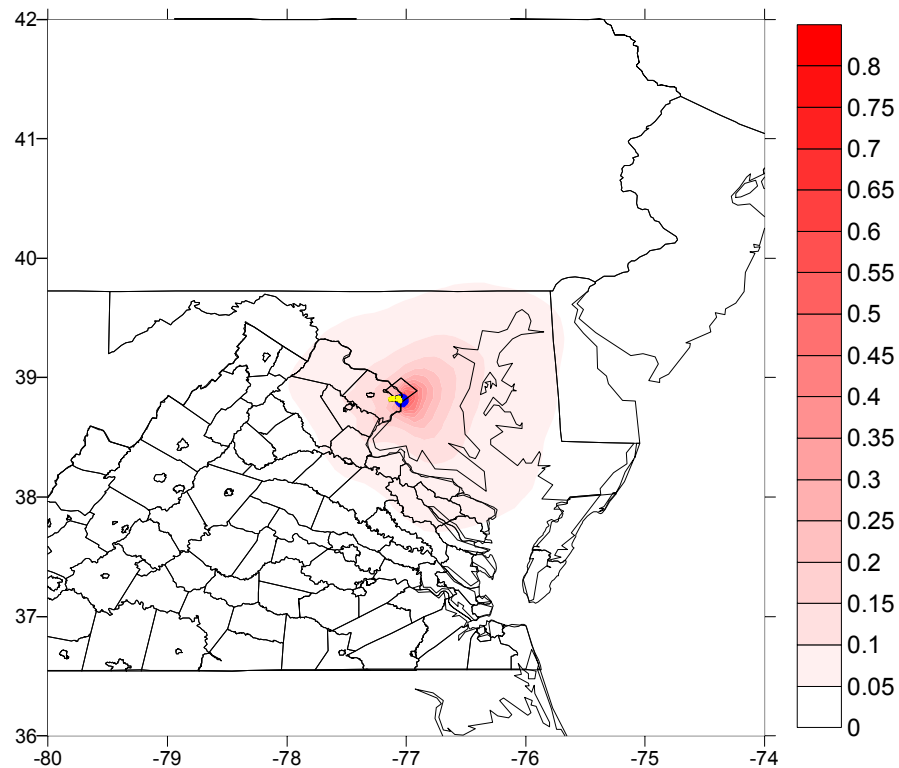
As expected, the concentration impacts are more diffuse, with a more gradual decrease in concentrations as a function of distance. The maximum secondary PM<sub>2.5</sub> concentration increment is approximately 0.24 µg/m<sup>3</sup>, occurring at a different spot within Washington, DC than the maximum primary PM<sub>2.5</sub> concentration increment, approximately 12 km from the Potomac River power plant. In general, the peak impact occurs at longer range than for primary PM<sub>2.5</sub>. Within Alexandria, the secondary PM<sub>2.5</sub> concentration increment ranges from 0.10-0.15 µg/m<sup>3</sup>, a lesser gradient than seen for primary PM<sub>2.5</sub> (Figure 5).

Figure 5: Annual average secondary PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the City of Alexandria and Washington, DC (in µg/m<sup>3</sup>).



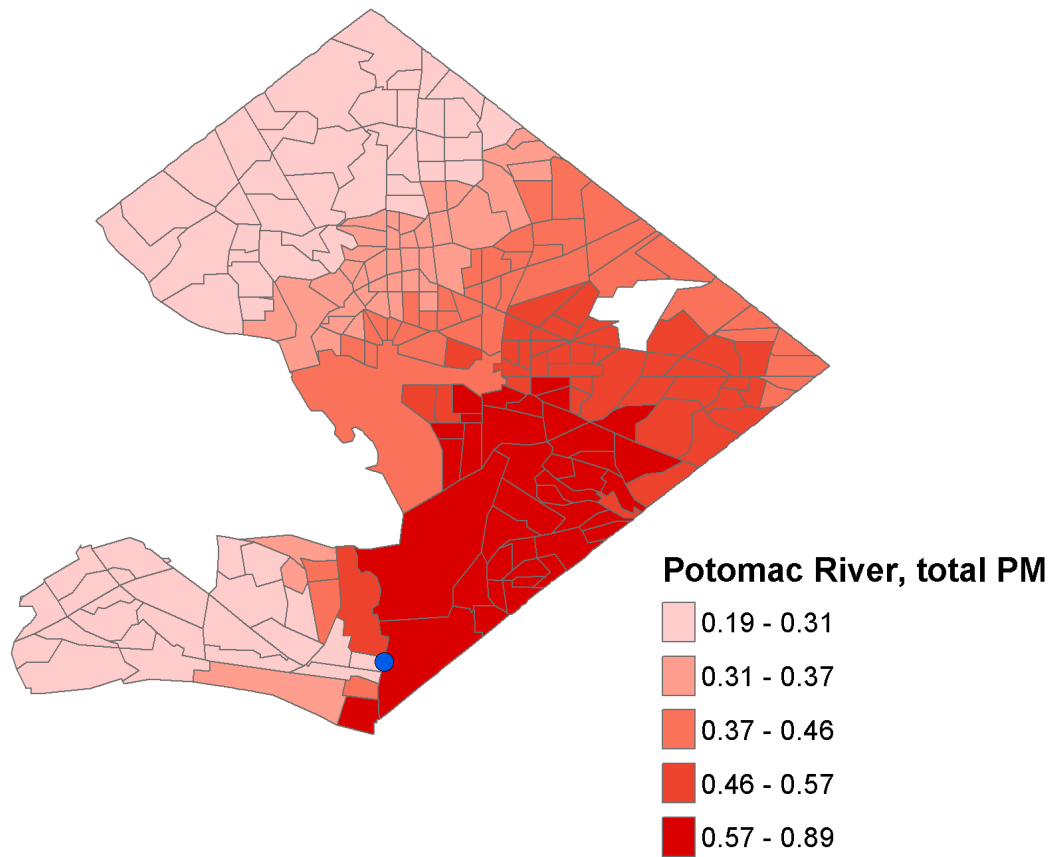
Finally, we can add up primary and secondary PM to yield total PM<sub>2.5</sub>. Figure 6 shows the annual average total PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant.

Figure 6: Annual average total PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the model region (in  $\mu\text{g}/\text{m}^3$ ).



As expected, the concentration pattern is somewhere in between the patterns for primary and secondary PM<sub>2.5</sub>. The highest total PM<sub>2.5</sub> concentration increment is approximately  $0.9 \mu\text{g}/\text{m}^3$ , at the same site in Washington, DC where the primary PM<sub>2.5</sub> increment was highest. This is not unexpected, since the maximum primary PM<sub>2.5</sub> increment is somewhat higher than the maximum secondary PM<sub>2.5</sub> increment. Within Alexandria, the total PM<sub>2.5</sub> concentration increment from the Potomac River power plants ranges between  $0.19$  and  $0.58 \mu\text{g}/\text{m}^3$  (Figure 7).

Figure 7: Annual average total PM<sub>2.5</sub> concentration increments associated with the Potomac River power plant across the City of Alexandria and Washington, DC (in  $\mu\text{g}/\text{m}^3$ ).



Now, how can these values be interpreted? As mentioned above, the annual average PM<sub>2.5</sub> concentration in Alexandria in 1999 (our case study modeling year) was about 14  $\mu\text{g}/\text{m}^3$ . This implies that, depending on the location in Alexandria, the Potomac River power plant contributes anywhere from 1-4% of the total ambient PM<sub>2.5</sub>. The obvious question is whether this constitutes a significant fraction or not. Although it implies that eliminating the Potomac River power plant would only decrease PM<sub>2.5</sub> concentrations by a relatively small percentage, the same argument is likely true for any single source taken in isolation. The more important questions are therefore what benefits could be obtained by alternative emission control plans, how those benefits compare across pollution sources, and whether the public health benefits of these emission controls justify the costs. In the next section, I address the question of whether controlling other power plants in the region would lead to greater or lesser concentration reductions within Alexandria than controlling Potomac River.

What are the impacts of the other four power plants on PM<sub>2.5</sub> concentrations in Alexandria, and how does this compare with the impact from Potomac River?

For this section, I only consider the impacts of the five power plants on PM<sub>2.5</sub> concentrations within the City of Alexandria, to answer the specific question of whether controlling higher-emitting power plants further away from Alexandria would provide greater or lesser benefits than controlling the Potomac River power plant. So, only “close in” figures are presented. As previously, I consider primary and secondary PM<sub>2.5</sub> separately before considering total PM<sub>2.5</sub>.

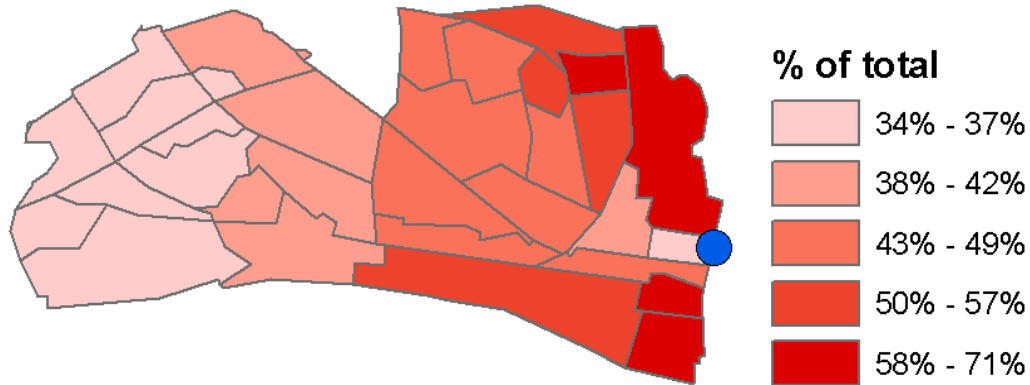
When considering primary PM<sub>2.5</sub>, because of the steep concentration gradient, one would expect that power plants further away from Alexandria would have a relatively small influence on concentrations within Alexandria, but that nearby upwind power plants would have a measurable influence. Indeed, this turns out to be the case. As shown in Table 2, the Potomac River plant is generally the greatest contributor to power plant primary PM<sub>2.5</sub> among the five power plants modeled, but Possum Point, Dickerson, and Chalk Point make some contributions. Figure 8 illustrates that the percentage of the total primary PM<sub>2.5</sub> impact from the five power plants that is contributed by Potomac River is as high as 70% near the facility, decreasing to 30-40% further away, with a similar spatial pattern as for primary PM<sub>2.5</sub> concentrations from Potomac River.

Table 2. Annual average PM<sub>2.5</sub> concentration increments within the City of Alexandria associated with five modeled power plants (in µg/m<sup>3</sup>).

Power plant	Primary PM <sub>2.5</sub> increment	Secondary PM <sub>2.5</sub> increment	Total PM <sub>2.5</sub> increment
Benning	0.001-0.002	0.003-0.004	0.005-0.006
Chalk Point	0.020-0.024	0.10-0.11	0.12-0.14
Dickerson	0.041-0.046	0.072-0.076	0.11-0.12
Possum Point	0.087-0.11	0.11-0.12	0.19-0.24
Potomac River	0.081-0.45	0.10-0.15	0.19-0.58
<b>Total</b>	<b>0.24-0.63</b>	<b>0.39-0.47</b>	<b>0.63-1.1</b>



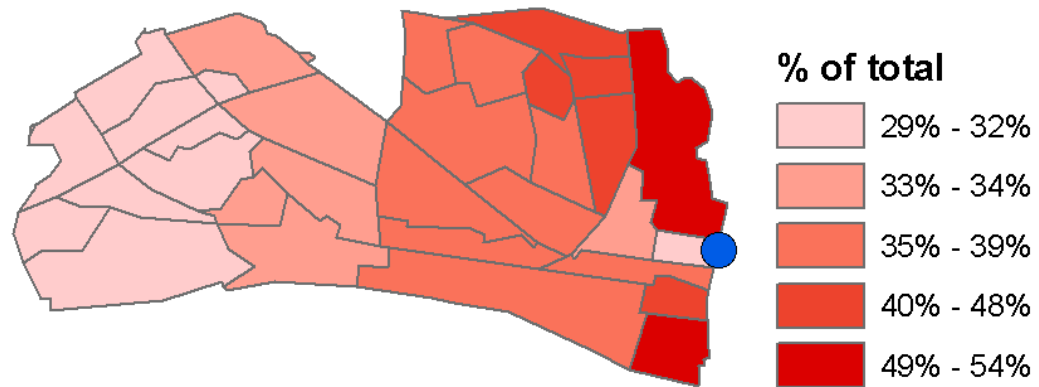
Figure 8: Percentage of the annual average primary PM<sub>2.5</sub> concentration increment in the City of Alexandria from the five power plants that is associated with the Potomac River power plant.



For secondary PM<sub>2.5</sub>, since the concentration gradient is not as steep, the relative contribution of the Potomac River power plant is somewhat lower and is more uniform across the City of Alexandria. The percentage contribution of Potomac River ranges from 25-33%, although in nearly all cases, it is the single largest contributor among the five power plants.

For total PM<sub>2.5</sub>, the Potomac River power plant contributes between 29% and 54% of the PM<sub>2.5</sub> concentration increment from the five modeled power plants, with higher contributions found closer to the plant (Figure 9). For five of the 34 census tracts, Possum Point makes a greater contribution to PM<sub>2.5</sub> levels than does Potomac River, but Potomac River is the largest contributor in the other 29 census tracts.

Figure 9: Percentage of the annual average total PM<sub>2.5</sub> concentration increment in the City of Alexandria from the five power plants that is associated with the Potomac River power plant.



In terms of the overall interpretation of these values, it is important to remember that the percentages represent the amount of the contribution from the five power plants that Potomac River provides, not the amount of total PM<sub>2.5</sub> exposure. The aggregate contribution of these five power plants to PM<sub>2.5</sub> levels in Alexandria ranges from about 0.63-1.1  $\mu\text{g}/\text{m}^3$  on an annual average basis. When compared with ambient PM<sub>2.5</sub> levels, this is about 4-8% of monitored concentrations.

What are the estimated health impacts in Alexandria associated with the five power plants?

As indicated in our published study (Levy *et al.*, 2002a), we estimated health impacts two different ways in our analysis. The first approach was to use the standard methodology employed in most studies, linking health evidence with concentrations directly. The second approach was to try to take account of factors that might influence susceptibility to air pollution – for example, diabetics have been shown to have greater risk of cardiovascular effects from air pollution exposure (Zanobetti and Schwartz, 2001). For this report, I focus on the first approach for simplicity's sake and to facilitate comparison with other studies.

In our study, we concluded that current emissions from the five power plants combined contribute to 270 deaths per year across the region, along with 80 cardiovascular hospital admissions (CHA) among the elderly and 190 pediatric asthma emergency room visits (ERV) per year. The number of deaths is higher than the less severe health outcomes because the morbidity outcomes are for a subset of diseases and ages, and because they are only based on short-term pollution exposures.

The question is: Of this total, what fraction occurs within Alexandria? Although particulate matter exposures from the five power plants are high in Alexandria when compared with the rest of the model region, the population of Alexandria represents about 0.2% of the population in the region. So, we would expect that only a small fraction of the total health impacts would occur in Alexandria.

Table 3 depicts the annual health impacts within Alexandria associated with each of the five power plants, using 1990 census data for comparability with our published study and with our model outputs. Of note, the population of Alexandria has increased from 111,183 to 128,283 from 1990 to 2000, a 15.4% increase, so the health impacts would be proportionately greater for the current and projected future population of Alexandria. However, the general conclusions are unchanged.

Table 3: Estimated annual public health impacts in the City of Alexandria associated with emissions from five power plants.

	Deaths/year	CHA/year	Asthma ERV/year
Benning	0.02	0.005	0.009
Chalk Point	0.4	0.1	0.2
Dickerson	0.4	0.1	0.2
Possum Point	0.7	0.2	0.4
Potomac River	0.9	0.3	0.4
<b>Total</b>	<b>2.3</b>	<b>0.7</b>	<b>1.2</b>
<b>% of total from Potomac River</b>	<b>37%</b>	<b>37%</b>	<b>36%</b>
<b>% of total in region</b>	<b>0.9%</b>	<b>0.9%</b>	<b>0.6%</b>

Some observations are necessary to place these estimates in context. First, the five power plants are estimated to contribute slightly over 2 deaths/year to the City of Alexandria. The baseline number of deaths in Alexandria each year in the 30+ age group (the assumed at-risk population for air pollution-related deaths) is approximately 800. So, our model is indicating that these five power plants contribute to about one out of 400 deaths, or 0.25%. It should also be noted that the number of annual deaths and morbidity outcomes contains some fractional values, which can best be interpreted when thinking about the long run – 2.3 deaths/year means that over a 10 year period, 23 deaths would be expected.

In addition, of the risk within Alexandria from the five power plants, about 37% can be attributed to the Potomac River power plant. This is a function of how much  $PM_{2.5}$  is contributed by each power plant (Figure 9), weighted by the number of people in each census tract. Finally, these health impacts within Alexandria are slightly less than 1% of the total health impacts across the region, as estimated in our original publication and reported above. This is greater than the population contribution of Alexandria to the region, because the  $PM_{2.5}$  contribution is relatively higher in Alexandria than in many parts of the region.

What are the estimated health benefits in Alexandria if emission controls were used at the five power plants?

Given this baseline level of mortality and morbidity, we can estimate the potential health benefits if the five power plants were to adopt Best Available Control Technology. As described above, this would involve substantial emission reductions that vary in magnitude across the pollutants and the plants, making the distribution of benefits slightly different than the distribution of current health impacts.

In our original study (Levy *et al.*, 2002a), we estimated that applying Best Available Control Technology to the five power plants would reduce health impacts across the region by 210 deaths, 59 cardiovascular hospital admissions among the elderly, and 140 pediatric asthma emergency room visits per year (from a baseline of 270, 80, and 190, respectively). As above, I address the question here of the fraction of the total benefits found within Alexandria. The results of this analysis are summarized in Table 4.

Table 4: Estimated annual public health benefits in the City of Alexandria if five power plants used Best Available Control Technology.

	Deaths/year	CHA/year	Asthma ERV/year
Benning	0.007	0.002	0.004
Chalk Point	0.3	0.09	0.2
Dickerson	0.3	0.09	0.2
Possum Point	0.5	0.2	0.3
Potomac River	0.5	0.2	0.3
<b>Total</b>	<b>1.7</b>	<b>0.5</b>	<b>0.9</b>
<b>% of total from Potomac River</b>	<b>31%</b>	<b>31%</b>	<b>31%</b>
<b>% of total in region</b>	<b>0.8%</b>	<b>0.8%</b>	<b>0.6%</b>

The benefits from emission controls are distributed similarly as the baseline impacts, with some minor differences. The contribution of Potomac River to benefits is slightly less than its contribution to baseline impacts (31% of the total from the five power plants, versus 37%). This is because the potential emission reductions are slightly greater for many of the other power plants. For example, Chalk Point, Dickerson, and Possum Point all have a greater baseline emission rate of SO<sub>2</sub> in lbs/million BTU than Potomac River, implying that a greater fraction of their current impacts will be reduced by meeting Best Available

Control Technology emission rates. However, controls at Potomac River would provide among the greatest benefits to public health in Alexandria, with essentially identical benefits available through controlling Possum Point.

### What do these findings mean (and not mean)?

The above figures and tables provide detailed information about the impacts of selected power plants in the Washington, DC area on air quality and public health in and around Alexandria. However, the crucial question is obviously what this means and does not mean for public policy.

When looking at current emissions, we can conclude that the Potomac River power plant is the largest single contributor to ambient  $PM_{2.5}$  in most parts of Alexandria among the five power plants modeled, but that the other four plants combined contribute 46-71% of the total from these five plants. When we look at the benefits of emission controls, the Potomac River power plant has a relatively lower contribution (31% of the total health benefits), but is still one of the two power plants contributing the most benefits (with Possum Point providing nearly identical benefits).

If we try to place the magnitude of the impacts from these five power plants in context, we see that current emissions contribute approximately  $0.6\text{--}1.1\ \mu\text{g}/\text{m}^3$  of  $PM_{2.5}$  on an annual average basis (4-8% of ambient concentrations), with emission controls reducing concentrations by  $0.5\text{--}0.7\ \mu\text{g}/\text{m}^3$  (3-5% of ambient concentrations). From one perspective, this may appear like a relatively small percentage, since 95-97% of  $PM_{2.5}$  would remain after these emission controls were implemented. However, it is important to compare this percentage with the concentration reductions that could be obtained through other emission control strategies. Because there are numerous power plants, millions of motor vehicles, other pollution sources, and some underlying background  $PM_{2.5}$ , one might anticipate that any small set of sources will contribute a similarly small fraction of ambient concentrations.

For example, using the results from a source-receptor matrix applied by US EPA in past regulatory impact analyses (US Environmental Protection Agency, 1999), if all light-duty and heavy-duty cars and trucks in the state of Virginia were eliminated (including both gasoline and diesel vehicles), annual average  $PM_{2.5}$  concentrations in Alexandria would decrease by approximately  $1.5\ \mu\text{g}/\text{m}^3$ . Since eliminating all vehicles from Virginia is obviously not a remotely plausible control strategy, the benefits for vehicle control strategies at the state level would be a small fraction of this total.

Applying the same source-receptor matrix to power plants, a 75% emission reduction from the five power plants we evaluated would reduce  $PM_{2.5}$  concentrations in Alexandria by  $0.3\ \mu\text{g}/\text{m}^3$ , while the same emission reduction at 502 other major power plants in the United States would reduce  $PM_{2.5}$

concentrations in Alexandria by an additional  $1 \mu\text{g}/\text{m}^3$ . Thus, the amount of concentration reduction available through controlling these five power plants is reasonably high in comparison with other plausible emission control strategies. Note that the absolute magnitude of benefits is slightly different with this source-receptor matrix than with our model, both because of differences in assumed emissions and model assumptions. Although the absolute numbers in this sample calculation may not be precisely correct, the relative values and general conclusions are well supported.

It is also important to keep in mind that, while the numbers above were presented without any characterization of uncertainty, there are clearly multiple factors that are uncertain and could influence the magnitude of the estimates. The emissions values that we used represent reported emissions in 1999, but current or future emissions may differ. Our atmospheric dispersion model (CALPUFF) has been approved by US EPA for modeling of long-range pollution transport, and we have found that the CALPUFF model yields similar health risk estimates as other models (Levy *et al.*, 2003). However, any dispersion model contains some inherent uncertainties.

In addition, since CALPUFF has been designed for long-range pollution transport, it is not ideal for understanding extremely small-scale pollution patterns. We chose CALPUFF because we were interested in estimating the total health benefits of pollution control, which is largely a phenomenon of long-range pollution transport. While the patterns at the census tract level appear reasonable, the findings from our modeling effort cannot be used to determine (for example) the precise impacts on individuals very close to the power plant. Addressing this question would require additional modeling using a different model, and perhaps with a focus on short-term rather than long-term concentrations.

Looking at the health estimates, the magnitude of the mortality and morbidity effects are based on observational epidemiological studies that are somewhat uncertain, because it is difficult to estimate a precise relationship between air pollution and health given other risk factors. The question about whether a threshold for health effects exists is obviously an important and controversial one, with major implications for the interpretation of our findings.

That being said, the assumptions made in our analysis are reasonable. Whenever possible, we chose values in the middle of the range of reported values, so that we are just as likely to have overestimated or underestimated health effects (Levy and Spengler, 2002; Levy *et al.*, 2002b). More generally, health risk assessments will always contain some underlying uncertainty. More studies can always be done, and better models are constantly being built. The



mere existence of uncertainty is not a sufficient reason to delay regulatory decisions, especially when the level of knowledge is already high and the stakes are substantial.

On that point, it is important to realize that a model of this sort is the only possible way to determine the relative contributions of Potomac River (or other power plants) to air pollution and health in Alexandria. Assuming that Potomac River contributes 1-4% of ambient  $PM_{2.5}$  in Alexandria, it would be impossible to use ambient monitors to estimate this contribution. Similarly, if the five power plants combined contribute 2 deaths per year in Alexandria, there would be no way to directly observe this influence, independent from other causes of death (especially since death certificates will not say “air pollution” on them). Thus, if we want to understand the influence of a subset of sources on the population of a city, we must apply a model like the one we developed.

Given these caveats, what conclusions can be drawn from this investigation? First, while the Potomac River power plant is not the dominant contributor to either deaths or  $PM_{2.5}$  concentrations in Alexandria, it is likely the single source that contributes most to  $PM_{2.5}$  levels in Alexandria. Reducing emissions from the five modeled power plants would lower  $PM_{2.5}$  concentrations in Alexandria and the surrounding region, although some  $PM_{2.5}$ -related health risks could still remain. It is also quite clear that decisions about emission controls at power plants need to take account of the regional health impacts, since local health impacts contribute a relatively small fraction of the total. At the same time, there are clear concentration gradients across and within cities, and it is important to understand how individuals would benefit from various emission control plans.

As mentioned at the beginning of the report, it is not possible to make specific policy recommendations based solely on our analyses. However, this report should provide a more detailed understanding of how local, regional, and national sources contribute to air pollution health risks in Alexandria, which can be used to inform future policy decisions.

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